The Properties of Galaxies in Low Density Regions from the ALFALFA Survey

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Abstract. Galaxies detected in the 21-cm line of neutral hydrogen (H I) from the on-going Arecibo Legacy Fast ALFA (ALFALFA) blind extragalactic H I survey have been cross-correlated with Sloan Digital Sky Survey (SDSS) Data Release 7 (Abazajian et al. 2009) in order to define a reference sample of H I content in regions of low galactic density. This observational sample will be used in the future to derive new standards of normal atomic gas content that allow a statistical investigation of the H I properties of galaxies in differing environments of the local universe. As a previous step, we compare here morphological indicators, like color or light concentration index, of ALFALFA detections and non-detections in low density regions. Our examination is extended also to a small data set of isolated galaxies. This kind of analysis is necessary in order to characterize as accurately as possible the type of galaxies that ALFALFA is detecting.

1. Introduction

The first study to establish rigorous standards of normalcy for the H I content of galaxies in the absence of external influences was carried out by Haynes & Giovanelli (1984), who used 288 galaxies with neutral hydrogen emission contained in the *Catalogue of Isolated Galaxies* (CIG, Karachentseva 1973) to define a control sample. In this work, it was demonstrated that, for a given Hubble type, the optical linear diameter of galaxies is the most accurate diagnostic tool for the H I mass. This measure of the H I content was reviewed and updated by Solanes, Giovanelli, & Haynes (1996) using a sample of 532 galaxies listed in the Zwicky et al. (1961–1968) magnitude-limited Catalog of Galaxies and Clusters of Galaxies located in the lowest density environments of the Pisces-Perseus supercluster region. The lack of H I dedicated surveys in those days forced the authors to deal with multiple galaxy data sets affected by incompleteness and selection effects that could not always be fully accounted for in the calculation of the standard measurements of the H I content.

This situation is now changing rapidly thanks to the on-going Arecibo Legacy Fast ALFA (ALFALFA) survey (Giovanelli et al. 2005), a blind, flux-limited extragalactic survey of the sky accesible to the Arecibo's antenna that is providing an homogeneous census of 21-cm line sources over a cosmologically significant volume of the local universe. In this work, we use the H I dataset from ALFALFA that will soon constitute the first massive public data release, to define a standard sample for the comparison of the H I content of galaxies

free of the potential observational biases mentioned above, and combine it with optical data from SDSS in order to inspect some of the intrinsic properties of ALFALFA sources.

The definition of a suitable standard of normalcy for the H I content necessitates a well-chosen control sample formed by galaxies with H I properties as less affected by the environment as possible. This requirement has led us to define our reference sample from ALFALFA detections in regions of low galactic density. This procedure, which is supported by previous works showing that the depletion of H I gas is a phenomenon essentially constrained to the inner regions of rich clusters and the densest groups of galaxies (e.g. Giovanelli & Haynes 1985; Solanes et al. 2001; Verdes-Montenegro et al. 2001), ensures a sufficiently large sample that allows a thorough statistical treatment of data.

In the present work, we also investigate the properties of a much smaller dataset of isolated galaxies, the objects which are presumably less affected by environmental processes.

2.   Low Density Region galaxy sample

The ALFALFA catalog consists of $\sim$6800 H I detections over ~ 1440 deg^2 on the Northern Hemisphere sky and with H I -masses within the range $10^7 \leq h^2 M_{HI}/M_\odot \leq 10^{10}$. We have restricted our attention to those ALFALFA galaxies which have an optical counterpart in SDSS and heliocentric velocities within the range $3000 \leq v_{\rm hel} \leq 15000$ km s^{-1}, in order to avoid large distance uncertainties for the closest objects as well as the gap in 21-cm line detections above 15000 km s^{-1} caused by radio frequency interference. For each candidate, and after correcting radial distances for peculiar motions following prescriptions by Blanton et al. (2005), we calculate the 3D distance to the 6*th* nearest neighbor in the SDSS complete spectroscopic survey (with r-band magnitude ≤ 17.77 mag). The corresponding estimate of the local density ρ_6 is corrected for Galactic extinction (Schlegel et al. 1998) and magnitude-limit effects by using the SDSS luminosity function (Blanton et al. 2001).

The Low Density Region (LDR) sample includes galaxies with local density below a certain threshold $\rho_{\rm thr}$. By applying the H I-deficiency estimator (Giovanelli & Haynes 1983) updated with the coefficients inferred in Solanes et al. (1996), we find that the H I content of galaxies inhabiting regions with local density below $\rho_{\rm thr} = 0.5$ galaxies/Mpc^3 is not correlated with the environment. We have also verified that this threshold allows to discard practically all galaxies located within $\sim$2-3 virial radii around rich Abell clusters.

In the top left panel of Figure 1, we compare the distributions of $g - r$ colors of SDSS and ALFALFA galaxies located in LDR in the volume of the sky (in z-space) where both surveys overlap. This comparison is repeated in the top right panel, but restricted to the subsets of LDR galaxies that verify the criterion used by Maller et al. (2009) to identify disk galaxies (axis ratio ≤ 0.55 or Sérsic index ≤ 3). As expected, most of ALFALFA detections ($\sim 92\%$) satisfy it, while about one non-detection out of every six is not a Maller et al.'s disk.

Inspection of the color distribution confirms that ALFALFA is detecting mainly blue galaxies. Even among those objects classified as disks by Maller et al.'s criterion, ALFALFA galaxies are also the bluest. Given the flux-limited nature

of the ALFALFA survey, this behavior becomes more accentuated with distance, i.e. the galaxies with the reddest colors, which are expected to be usually less rich in H I, are preferently detected at closer distances. We also find that ALFALFA detections tend to show large values of the inverse concentration index, a characteristic of late-type galaxies.

3.   Isolated galaxy sample

We have compared the colors of the members of the LDR galaxy sample defined in Section 2. with those belonging to a data set of isolated galaxies that are as unperturbed as possible by environmental mechanisms. The latter has been defined applying different isolation criteria, such as the one based on angular diameter used by Karachentseva (1973) in the CIG and its updated version adopted by Allam et al. (2005) for the SDSS. We have also defined our own isolation criterion similar to others found in the literature that combine photometric and spectroscopic information: a candidate galaxy i is considered to be isolated if any neighboring galaxy j with apparent magnitude $m_j \leq m_i + 1.5$ mag is located further away than 280 h^{-1} kpc ($\sim$ 400 kpc for $h = 0.7$).

As already revealed by previous works (e.g. Verley et al. 2007), while it is true that isolated galaxies avoid the densest regions of the universe, we find that some of them may inhabit regions of moderate local density in which ρ_6 is larger than the density threshold we have used to define our LDR sample. To avoid this problem, membership for our isolated galaxy sample is restricted to LDR objects only.

In sharp contrast with LDR galaxies, dominated by blue objects, the color distribution of our isolated sample demonstrates that any technique used to identify isolated galaxies from the difference in apparent magnitude between neighbors *always* favours the selection of brighter and, hence, redder objects (Figure 1). This is consistent, for instance, with the results reported in the work by Allam et al. (2005), in which they obtained an isolated galaxy sample from SDSS with a concentration index distribution that suggested a morphological composition fifty-fifty between early and late galaxy types.

On the other hand, we find that, from a statistical point of view, the H I contents of our isolated galaxies are essentially identical to those of our LDR sample galaxies, thus confirming that substantial gas depletion takes place mainly in high density environments.

4.   Summary and Future Work

We have introduced the reference data set of ALFALFA detections that is going to be used in the calculation of new standards of the H I content of galaxies. The present comparison between some characteristics of SDSS galaxies in LDR detected and undetected by the ALFALFA survey is just a first small step towards setting up a suitable framework for the investigation of the H I content of galaxies in a wide range of environments of the local universe.
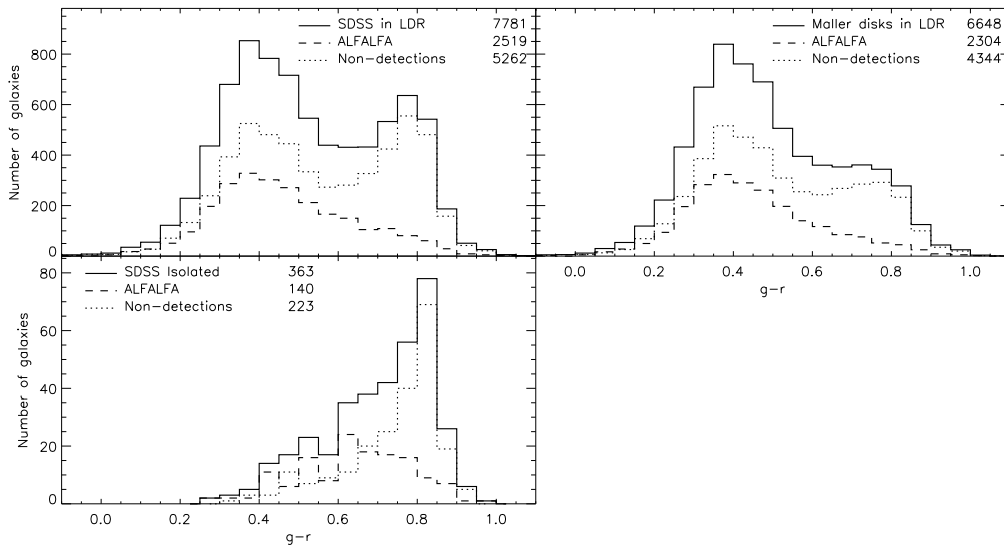
Figure 1.   *Top left:* SDSS $g - r$ color of a subset of the SDSS spectroscopic complete sample in the region overlapping with ALFALFA survey (solid). We have selected only galaxies in low density regions with velocities within $3000 \le v_{\mathrm{hel}} \le 15000$ km s^{-1}. The sample is splitted into objects whose H I is detected by ALFALFA (dashed line), and non-detections (dotted line). *Top right:* same as above, but only for those objects identified as disks according to the Maller et al.'s 2009 criterion. *Bottom left:* same as above, but for objects classified as isolated applying our spectrophotometric criterion.

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